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Sports-related testing protocols are required to reveal trunk stability adaptations in high-level athletes

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ABSTRACT

Trunk/core stability is considered a key component of training programs, because it could contribute to prevention of low-back and lower-limb injuries and to sports performance. Based on the specificity principle, sports-related trunk stability tests would be required in elite sports performance. However, there may be some generic qualities underlying trunk stability that can be assessed with nonspecific protocols, which are broadly used in sport and rehabilitation. To assess whether specific tests are needed in a high-performance context, we analyzed the influence of specialization in sports with large but qualitatively different balance control demands (judo and kayaking) on trunk stability and compared high-performance athletes with recreational athletes without a specific training history. Twenty-five judokas, sixteen kayakers and thirty-seven recreational athletes performed two trunk stability protocols: *sudden loading*, to assess trunk responses to external and unexpected perturbations; *stable and unstable sitting*, to assess the participant's ability to control trunk while sitting. Within-session test-retest reliability analyses were performed to support the between-groups comparison. Judokas showed lower angular displacement (0.199 rad) against posterior loading than kayakers (0.221 rad) probably because they are frequently challenged by higher sudden loads while they are pushed or pulled. Kayakers showed lower error (<6.12 mm) of center of pressure displacements than judokas especially during dynamic task while sitting on an unstable seat (>7.33 mm), probably because they train and compete seated on unstable surfaces. Importantly, judokas and kayakers obtained better results than recreational athletes only in those tests designed according to the specific demands of each sport ($p < 0.050$). In conclusion, specific-sport training induces specific trunk stability adaptations, which are not revealed through nonspecific tests.

1. Introduction

Trunk or core stability has been operationally defined as the "ability to control the trunk in response to internal and external disturbances, including the forces generated by distal body segments, as well as resulting from expected or unexpected perturbations" [1,2]. Trunk stability is considered a key component of training programs because its improvement could aid in primary and secondary prevention of low back disorders [3] and lower limb injuries [2,4], and it might contribute to sport performance, as it would facilitate the transmission of forces [5] and would increase whole-body balance [1].

Trunk stability is not likely a one-dimensional concept, and its quality seems to depend on the context [6]. Perturbations of trunk movement can vary in amplitude and can range from self-imposed

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and predictable to externally imposed and unpredictable. In addition, depending on the task, subjects may prefer to stabilize their trunk relative to their pelvis or the orientation of their trunk in space [7]. Finally, the weighting of sensory modalities in the control of trunk posture is dependent on the mechanical stability of the surface providing support [8].

Considering the potential specificity of trunk control, the quality of an individual's control may not be transferrable from one situation to another. In sports, it may be expected to find athletes who show excellent trunk performance in one task (i.e. sustaining a rugby tackle) but not in another task (i.e. balancing on a slackline). In contrast, it is quite common to use only one or a few generic tests, such as static holding of a specific trunk posture against gravity, regardless of the sports requirements [9,10]. If trunk stability is context dependent, sport-related protocols should be used to assess trunk stability in athletes and also training would need to be context dependent. However, a recent cross-sectional study by Glofcheskie [11] found that both, golfers and runners showed better trunk control in response to sudden loading, better balance control on an unstable seat and better trunk proprioception than non-athletes, suggesting there may be more generic qualities underlying good trunk control that can be trained in different ways. Therefore, further research is required to elucidate to what extent trunk stability depends on the context and in which conditions generic or specific tests are needed.

In this study, we compared different athletic populations in several trunk stability tests, to assess whether specific training leads to high performance on sport-related testing. We assessed sudden trunk loading and trunk balancing protocols in high-level judokas and kayakers and in less specifically trained recreational athletes. The aims of this study were 1) to analyze the influence of specialization in sports with large but qualitatively different balance control demands on trunk stability (i.e., judo and kayaking), and 2) to compare high performance athletes with recreational athletes without a specific training history. Based on the specificity assumption, it was hypothesized that judokas would show better trunk control after sudden perturbations than kayakers and recreational athletes, as they are frequently challenged by high sudden loads while training and competing, and that kayakers would show better trunk control in unstable sitting than judokas and recreational athletes, since they train and compete seated on unstable surfaces. In addition, we hypothesized that judokas and kayakers would not show better performance than recreational athletes on tests not designed to reflect the sports-specific demands described above.

2. Methods

2.1. Participants

Twenty-five judokas (age: 24.20 ± 7.40 years; height: 1.74 ± 0.07 m; mass: 74.76 ± 11.17 kg; HAT (head, arms and trunk) moment of inertia (I_{HAT}): 5.10 ± 1.26 kg·m^2), sixteen kayakers (age: 22.47 ± 8.16 years; height: 1.74 ± 0.08 m; mass: 70.73 ± 11.38 kg; I_{HAT}: 4.40 ± 1.06 kg·m^2) and thirty-seven recreational athletes (age: 24.00 ± 2.76 years; height: 1.76 ± 0.06 m; mass: 74.77 ± 8.83 kg; I_{HAT}: 5.41 ± 1.05 kg·m^2), took part in this study. I_{HAT} was calculated according to Winter [12]. The HAT center of mass position was estimated at 62.6% of the torso length between the greater trochanter to the glenohumeral joint. The HAT mass was calculated as 67.8% of the total body mass. Finally, I_{HAT} was calculated as follows:

$$I_{HAT} = m^* x^2$$

where m is HAT mass and x is HAT center of mass distance to L4-L5 joint.

The recreational athletes were physically-active men with a work-out frequency of 2–3 days per week. The judokas and kayakers were competitive male athletes and had more than 4 years of experience in national and/or international championships. None of the participants reported a recent history of back injury, abdominal surgery or inguinal hernia, and neurological or musculoskeletal disorders. Participants' written informed consent was obtained prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the University Office for Research Ethics.

2.2. Experimental procedure

Two protocols were performed to evaluate different trunk stability parameters in the following order [13]: 1) *sudden loading protocol* to assess trunk responses to external, quick and unexpected perturbations in different directions; 2) *stable and unstable sitting protocol* to assess the ability to control trunk posture and motion while sitting. Both protocols were performed in seated position with leg movement restriction to reduce lower limb influence and thus to focus the stability analysis on the trunk structures.

Prior to testing, participants performed a warm-up which consisted of 5 min cycling at 75 revolutions/minute on a cycle-ergometer, 2 sets of 15 crunches and back extensions on a Roman chair. A 30 s rest was given between sets. Taking into account that few studies have analyzed the reliability of the sudden loading and unstable sitting protocols and that Springate [14] recommend to use more than 25-30 participants for an accurate estimation of random error, we performed within-session test-retest reliability analysis using the 37 recreational athletes.

2.3. Sudden loading protocol

To assess trunk responses to external, quick and unexpected perturbations in different directions (anterior, posterior and lateral-right side), participants were placed in a semi-seated position restricting hip motion (Fig. 1). This position promoted a neutral spine posture and elastic equilibrium [15]. A pneumatic-piston, attached to a harness via a steel cable tensioner, pulled with 4.2 bars of pressure and 0.5 m/s of speed to load the trunk. The cable was aligned horizontally with the HAT center of mass position [12]. The magnitude and timing of the perturbation was measured using a load-cell (MLP-100, Transducer-Techniques Inc., Temecula, CA, USA), attached to the piston. The force signals were amplified, and A/D converted (16 bit resolution over ± 5 V) at 1000 samples/s. Biofeedback of load-cell forces was provided in real time to keep participant's forces constant (25–27.5 N) prior to the sudden perturbation. Participants were instructed to maintain a neutral spine posture without pulling on the load-cell before loading and not to respond voluntarily to the perturbation. Trunk kinematics were recorded at 200 samples/s with seven T10 cameras of the Vicon 3D-motion analysis system (Vicon MX, Oxford, UK) using three passive retro-reflective markers over the L5 spinous process, and the harness. Data were reconstructed using Nexus 1.8.2 software (Vicon MX. Oxford, UK). Five sudden perturbations were applied in each direction, with 1 min rest between trials and 5 min rest between directions. Each perturbation took place without warning within a 15 s window. Participants were blinded with a mask. The order of the perturbation directions was balanced over participants.

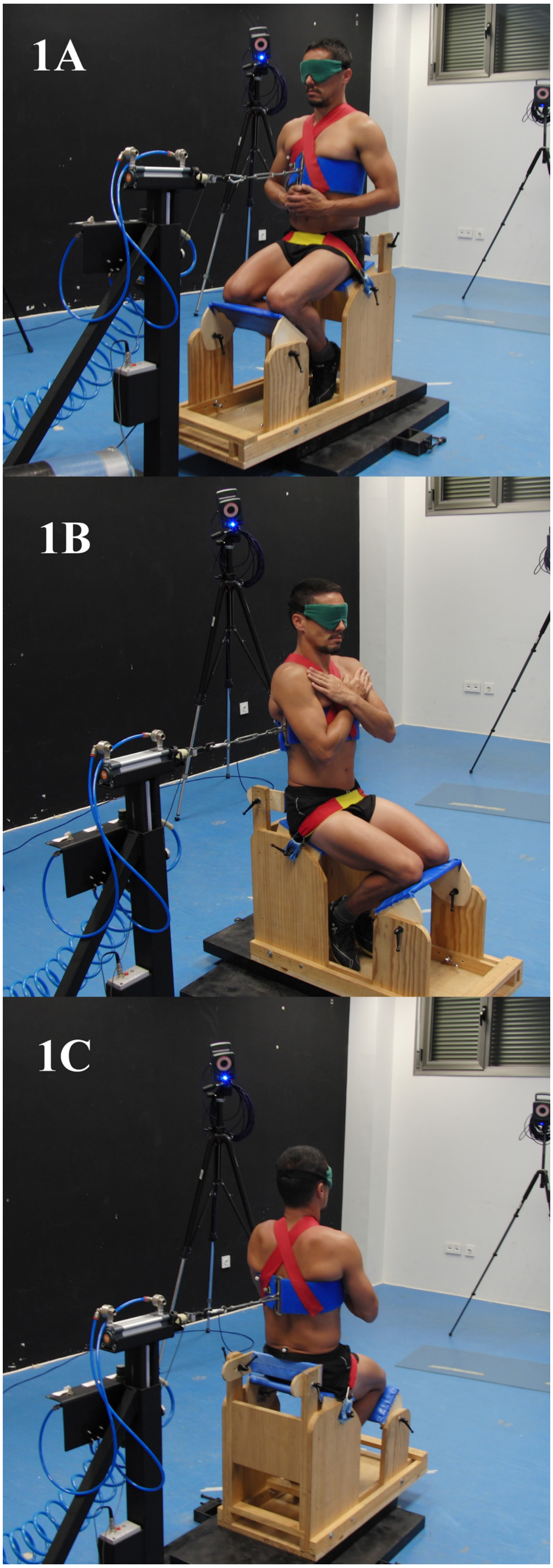

Fig. 1. Set-up for applying loads using a pneumatic pulling mechanism in the anterior (1A), right-lateral (1B) and posterior (1C) loading directions.

2.4. Stable and unstable sitting protocol

To assess the subject's ability to control trunk posture and motion, participants performed different tasks while sitting on an unstable or a stable seat (Fig. 2) with arms crossed over the chest and the legs strapped to the seat (90° knee flexion). The unstable seat had a polyester-resin hemisphere attached to the bottom (radius: 35 cm; height: 12 cm). The seats were placed on a force-plate (9286AA, Kistler, Switzerland) sampling at 1000 Hz. Feedback of the center of pressure (CoP) displacement was provided in real time (Fig. 2). Additionally, a target point was presented in several trials, to assess the subject's ability to adjust his CoP position to this point. Participants performed 2 static and 3 dynamic trials on both seats. One of the static trials was performed without visual feedback, in which participants were asked to sit still in their preferred seated position; and the other trial was performed with visual feedback, in which participants were instructed to align their CoP position with the target point located in the center of the screen. During the dynamic trials, participants were asked to track the target, which moved over three possible trajectories (anterior-posterior, medial-lateral and circular). During the dynamic conditions, the amplitude of target point displacement corresponded to a HAT center of mass inclination angle of 4°. The target point took 20 s to complete a cycle (0.05 Hz). The target point position was readjusted prior to each trial by averaging the CoP position during a 6 s static data collection without visual feedback. Each trial lasted 70 s with 1 minutes rest between trials. In the unstable conditions, all participants were able to maintain the sitting position without grasping the support rail. The full protocol was performed twice. To assess if this long balance protocol using piezoelectric force platform could lead to a drift in the force signal, 10 min of data were collected while a weight was placed on the force-plate (591 N). The small changes in vertical-force (0.16 N – 0.27%) and the standard deviation of the COP (<0.030 mm) across the trial indicated that the influence of drift on outcomes was very small.

2.5. Data analysis and reduction

To characterize the response to sudden load moment applied to the torso, maximum trunk angular displacement (θ_{max}), stiffness (K) and damping (β) were calculated according to Cholewicki et al. [16]. In our data, K and β parameters had lowest error and highest reliability when 22 data points were analyzed (110 ms). Because voluntary responses do not usually occur in the first 120–150 ms after perturbation, K and β represent an effective stiffness and damping combining intrinsic muscle properties and reflex responses [16]. θ_{max}, K and β obtained from the last two trials were used for the within-session reliability analysis, and were averaged over the best three trials (lower θ) per direction for between-groups comparisons.

For sitting tests, the COP time-series were subsampled (20 samples/s) and low-pass filtered (4th-order, zero-phase-lag, Butterworth, 5 Hz cut-off frequency) [17], as there is little physiological significance to the COP signal content above 10 Hz [18]. The first 10 s of each trial were discarded to avoid non-stationarity related to the beginning of the trial. We used the mean radial error (MRE) to quantify the trunk performance. MRE was calculated as the average of vector distance magnitude (mm) of the CoP from the target point or from the participant's own mean CoP position [19] for trials with and without visual feedback, respectively. Both trials of each condition were used for the within-session reliability analysis. The best trial of each condition (lower MRE) was used for between-groups comparisons.

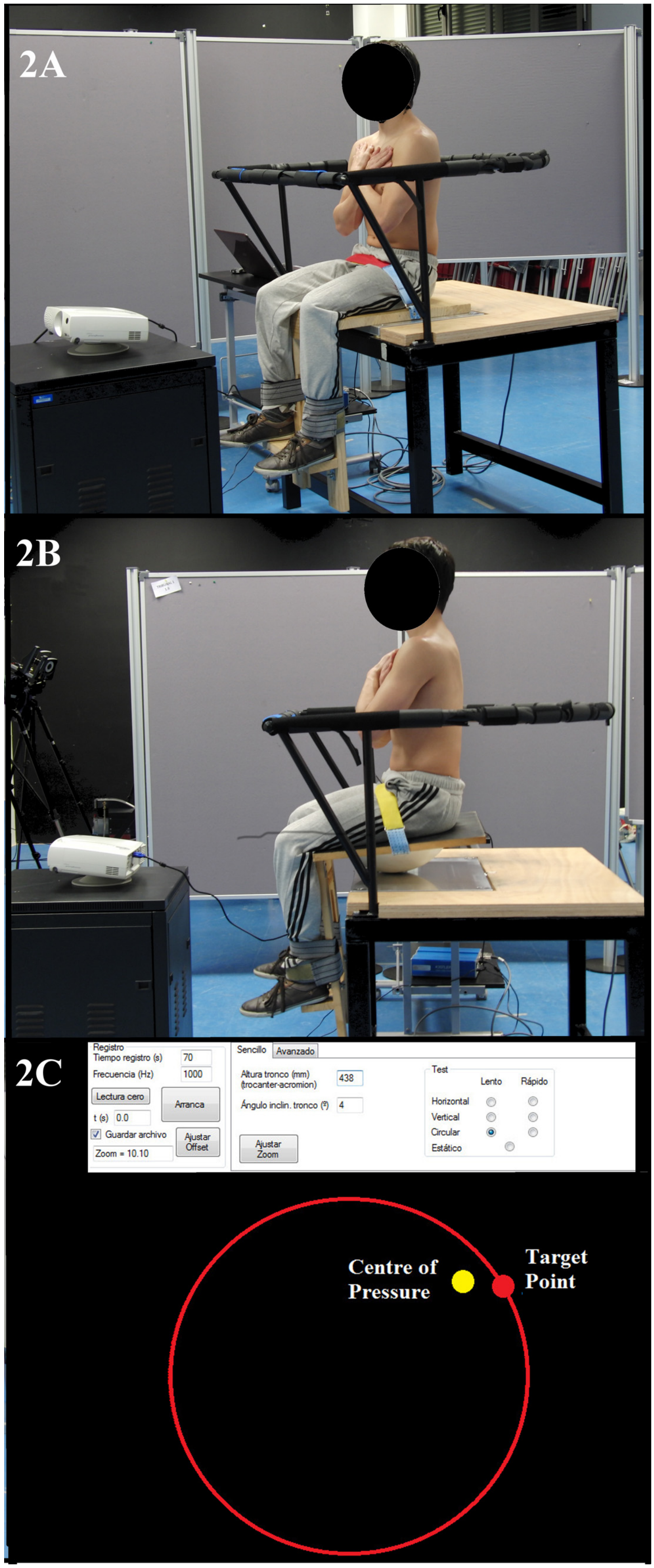

Fig. 2. Set-up for the balance sitting test. The pictures show a participant performing a sitting task on the stable (2A) and unstable (2B) seat, and the visual feedback (2C) provided to the participants (center of pressure and a target point). The red path is shown in this Picture 2C to clarify the trajectory, but it was not presented to the participant during the trial.

2.6. Statistical analysis

The intra-class correlation coefficient ($ICC_{2,1}$) and the standard error of measurement (SEM) were calculated to assess test-retest relative and absolute reliability respectively [20]. ICC scores higher than 0.70 were classified as high [21]. SEM was calculated as the standard deviation of the difference between 2 scores divided by $\sqrt{2}$. Then, SEM was divided by the mean and expressed as a percentage (%). Normality was examined using the Kolmogorov-Smirnov statistic. One-way independent-measures ANOVAs were performed to investigate the between-groups differences. I_{HAT} was used as covariate for the sitting protocol to ensure that between-groups differences were not influenced by trunk anthropometry. Partial eta-squared (η_p^2) was calculated as a measure of effect size. Post-hoc analysis with Bonferroni adjustment was used for multiple comparisons. Threshold for significance was set at $p < 0.05$. Finally, known-group validity was estimated using a Receiver Operating Characteristic (ROC) Curve for those variables which showed significant differences between groups. The resultant area under the ROC curve (AUC) was tested against a value of 0.50 (no discrimination).

3. Results

θ_{max}, K and β from the sudden loading protocol ($0.90 < ICC < 0.97$; $3.5\% < SEM < 14.8\%$) and MRE of the dynamic unstable sitting conditions ($0.85 < ICC < 0.93$; $9.2\% < SEM < 10.1\%$) showed a high reliability (Table 1). Regarding ANOVA results, only MRE from the sitting test showed a significant decrease between test and retest.

Concerning between groups differences, judokas showed higher K after lateral loading than the other groups (AUC = 0.724; K = 918 N*m/rad; sensitivity = 73.9%; specificity = 62.7%), lower θ after lateral loading than recreational athletes (AUC = 0.719; θ=0.070 rad; sensitivity = 68.0%; specificity = 62,7%), and lower θ after posterior loading than kayakers (AUC = 0.722; θ=0.217 rad; sensitivity = 72.0%; specificity = 62.5%) (Table 2). No differences were found between kayakers and recreational athletes for any loading direction.

Kayakers showed better trunk control than judokas and recreational athletes in stable and unstable sitting in most of the experimental conditions (Table 2 and Fig. 3). MRE from USCD condition showed the best AUC values (AUC = 0.849; MRE = 6.76 mm; sensitivity = 75.0%; specificity = 75.8%). ANCOVAs with I_{HAT} did not affect the differences between groups. No differences were found between judokas and recreational athletes for any trunk balancing task.

4. Discussion

We analyzed the effects of specializing in judo and kayaking and less specific training in recreational athletes on trunk responses against perturbations and trunk balancing, with the final aim of assessing whether specific tests are needed in a high performance context. Based on reliable measures, our main results highlight the sport-specificity of trunk stability protocols, as judokas showed better trunk responses against lateral and posterior loading, while kayakers showed better trunk balance control while sitting. Conversely, these high-performance athletes did not show better results than recreational athletes when they were assessed trough those tests not designed according to their specific sport demands. Thus, specific sport training seems to induce specific trunk stability adaptations which may be relevant for sport performance, but these were not revealed trough nonrelated testing protocols.

Given the lack of studies evaluating the reliability of the sudden loading and unstable sitting protocols [22], the reliability of our protocols was assessed to support the between-groups comparisons. Variables from sudden loading protocol and MRE for the dynamic unstable sitting showed an adequate reliability and therefore, they are suitable to test differences between groups. It is noteworthy that only the most difficult conditions of the sitting protocol showed good reliability, probably because the most difficult conditions require tighter neuromuscular control, resulting in a lower variability [23]. Based on ANOVA results (Table 1),

Table 1
Descriptive statistics (mean ± SD) and relative ($ICC_{2,1}$) and absolute (SEM) within-session reliability of the parameters obtained during the different protocols.

Protocols and variables			Test	Retest	F	p	$ICC_{2,1}$	SEM (%)
Sudden loading protocol	θ	Anterior	0.087 ± 0.019	0.087 ± 0.018	.001	.987	0.97	3.8
		Lateral	0.077 ± 0.020	0.078 ± 0.021	.015	.904	0.95	5.8
		Posterior	0.200 ± 0.027	0.205 ± 0.029	2.626	.114	0.94	3.5
	K	Anterior	1408.8 ± 540.9	1443.2 ± 423.7	1.777	.191	0.96	7.8
		Lateral	817.8 ± 317.9	784.3 ± 272.8	1.293	.263	0.90	11.8
		Posterior	564.9 ± 130.1	567.5 ± 150.4	.204	.654	0.97	4.4
	β	Anterior	406.2 ± 311.4	408.8 ± 315.6	.016	.901	0.96	14.8
		Lateral	729.5 ± 273.9	748.2 ± 278.7	.801	.377	0.91	11.3
		Posterior	78.9 ± 39.9	75.5 ± 40.7	1.254	.290	0.93	10.8
Stable and unstable sitting protocol	MRE	SSNF	0.99 ± 0.30	1.05 ± 0.34	.485	.491	0.12	32.8
		SSWF	0.92 ± 0.38	0.79 ± 0.16	6.104	.018	0.41	34.7
		SSML	2.41 ± 0.51	2.15 ± 0.61	12.958	.001	0.62	13.1
		SSAP	2.30 ± 0.49	2.14 ± 0.32	4.869	.034	0.70	13.8
		SSCD	3.64 ± 1.24	3.01 ± 0.72	11.911	.001	0.80	11.2
		USNF	6.44 ± 2.25	5.66 ± 1.68	5.856	.021	0.66	19.6
		USWF	6.22 ± 2.23	5.05 ± 1.60	24.145	.000	0.74	18.1
		USML	7.99 ± 2.80	7.19 ± 2.52	14.098	.001	0.93	9.3
		USAP	7.55 ± 1.98	6.93 ± 1.73	11.108	.002	0.85	10.1
		USCD	10.15 ± 3.04	8.33 ± 2.50	61.239	.000	0.91	9.2

Repeated measures ANOVA.
$ICC_{2,1}$: intraclass correlation coefficient; SEM: standard error of measurement.
θ (rad) = trunk angular displacement; K (N*m/rad) = trunk stiffness coefficient; β (N*m*s/rad) = trunk damping coefficient.
MRE = Mean radial error (mm); Trunk sitting conditions: stable sitting without feedback (SSNF); stable sitting with feedback (SSWF); stable sitting while performing medial-lateral displacements with feedback (SSML); stable sitting while performing anterior-posterior displacements with feedback (SSAP); stable sitting while performing circular displacements with feedback (SSCD); unstable sitting without feedback (USNF); unstable sitting with feedback (USWF); unstable sitting while performing medial-lateral displacements with feedback (USML); unstable sitting while performing anterior-posterior displacements with feedback (USAP); unstable sitting while performing circular displacements with feedback (USCD).

Table 2
Differences between kayakers, judokas and recreational athletes for the parameters obtained during the different protocols.

Protocols and variables			Recreational Athletes (n = 37)	Judokas (n = 25)	Kayakers (n = 16)	F	p	η_p^2
Sudden loading protocol	θ	Anterior	0.086 ± 0.019	0.092 ± 0.017	0.908 ± 0.017	.866	.425	.023
		Lateral	0.076 ± 0.019	0.066 ± 0.013[a]	0.067 ± 0.015	3.254	.045	.087
		Posterior	0.207 ± 0.026	0.199 ± 0.028	0.221 ± 0.024[b]	3.236	.045	.079
	K	Anterior	1461.2 ± 492.2	1560.8 ± 548.5	1341.5 ± 582.8	.829	.440	.022
		Lateral	807.9 ± 294.3	1111.6 ± 326.5[a]	941.4 ± 370.4	6.107	.004	.149
		Posterior	544.2 ± 134.3	585.8 ± 126.4	506.0 ± 119.8	1.925	.153	.049
	β	Anterior	402.0 ± 292.4	380.6 ± 153.0	450.9 ± 275.12	.376	.688	.010
		Lateral	744.7 ± 228.0	769.7 ± 303.3	689.7 ± 194.6	.500	.609	.014
		Posterior	76.8 ± 39.8	90.5 ± 36.2	72.6 ± 31.1	1.465	.238	.038
Stable and unstable sitting protocol	MRE	SSNF	0.90 ± 0.30	0.99 ± 0.36	0.93 ± 0.26	.601	.551	.016
		SSWF	0.73 ± 0.38	0.75 ± 0.38	0.86 ± 0.52	.588	.558	.015
		SSML	2.06 ± 0.39	2.35 ± 0.64	1.80 ± 0.52[b]	5.999	.004	.138
		SSAP	2.05 ± 0.46	2.15 ± 0.41	1.67 ± 0.31[ab]	7.144	.001	.160
		SSCD	2.98 ± 0.70	3.33 ± 1.18	2.44 ± 0.53[b]	5.217	.008	.122
		USNF	5.27 ± 1.50	5.66 ± 1.80	3.91 ± 1.12[ab]	6.688	.002	.151
		USWF	4.95 ± 1.43	4.97 ± 1.35	3.89 ± 1.07[ab]	4.045	.021	.097
		USML	6.98 ± 2.36	7.33 ± 2.08	5.14 ± 0.93[ab]	6.111	.003	.140
		USAP	6.78 ± 1.71	6.99 ± 1.50	5.42 ± 1.02[ab]	5.792	.005	.134
		USCD	8.31 ± 2.51	8.63 ± 2.64	6.12 ± 0.94[ab]	6.448	.003	.147

ANOVA with a between-subject factor.
Post hoc analyses with Bonferroni adjustment were used for multiple comparisons: [a]Significantly different from "recreational athletes". [b]Significantly different from "Judokas".
θ (rad) = trunk angular displacement; K (N*m/rad) = trunk stiffness coefficient; β (N*m*s/rad) = trunk damping coefficient.
MRE = Mean radial error (mm); Trunk sitting conditions: stable sitting without feedback (SSNF); stable sitting with feedback (SSWF); stable sitting while performing medial-lateral displacements with feedback (SSML); stable sitting while performing anterior-posterior displacements with feedback (SSAP); stable sitting while performing circular displacements with feedback (SSCD); unstable sitting without feedback (USNF); unstable sitting with feedback (USWF); unstable sitting while performing medial-lateral displacements with feedback (USML); unstable sitting while performing anterior-posterior displacements with feedback (USAP); unstable sitting while performing circular displacements with feedback (USCD).

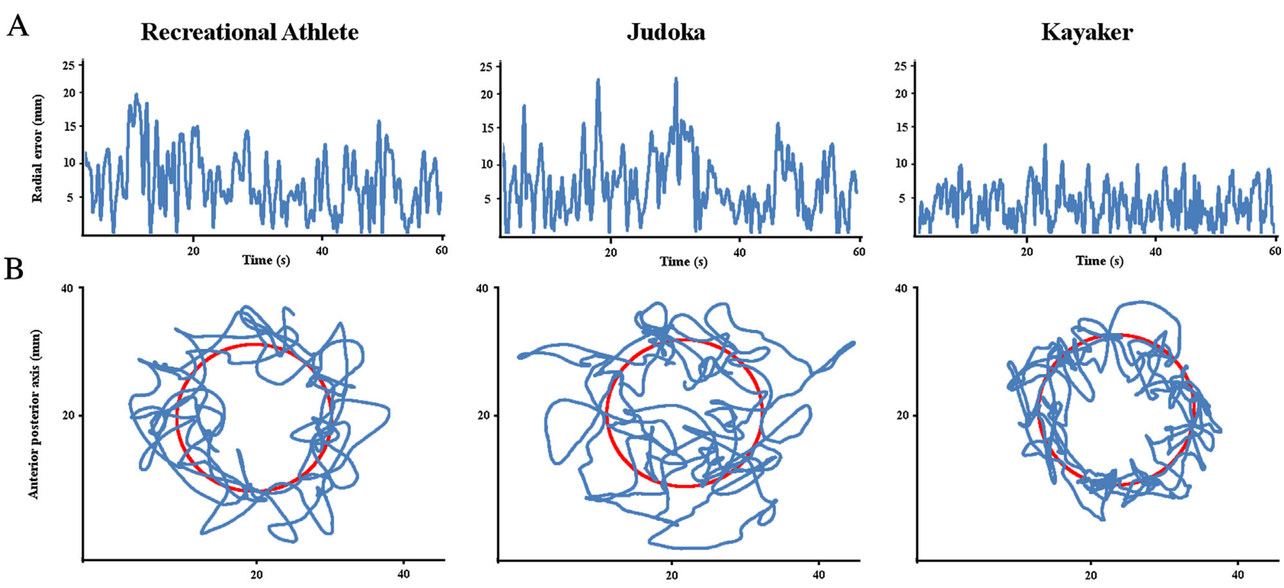

Fig. 3. Examples of the radial error (A) and the center of pressure displacement regarding the target point trajectory (B) of a recreational athlete, a judoka and a kayaker while performing circular displacements with feedback on the unstable seat.

the increase of trunk control in the sitting protocol between trial suggests that those tasks are susceptible to change due to learning [24] and need a longer familiarization period to reduce these learning effect.

In line with our hypotheses, judokas showed better responses after lateral and posterior perturbations than recreational athletes and kayakers respectively, while kayakers showed better trunk control in most of the sitting conditions than judokas and recreational athletes (Table 2). ROC analyses indicate that specific tests allow discriminating between groups. Thus suggests that specific sport training induces specific trunk stability adaptations. Although judokas did not show better results against sudden loading in all directions, these results are in line with previous findings, in which judokas showed higher stability against sudden perturbations than recreational athletes in upright stance [25]. These previous and our current findings could be explained by specific exertions that judokas do in training and competing, as they have to cope with high sudden forces that challenge their stability during offensive-defensive techniques [25,26]. Generalizing from findings on lower limb electromyography [25], the high quality of trunk response after loading in judokas could be related to short muscle activation latencies after sudden perturbations [25,27]. Alternatively, it could be related to specific anatomical adaptations of judo training; judokas have large trunk muscle cross-sectional areas [28], especially of the abdominal obliques, which could contribute to trunk stiffness and limit trunk displacement against sudden loading [29]. Regarding the kayakers, their better trunk control while sitting seems to be logically related to the specific exertions they do while kayaking, where they are used to apply forces and response to small continuous perturbations while sitting on unstable surfaces, using their upper body to keep the boat balanced, to reduce hydrodynamic drag and to improve paddling efficiency [30]. Although kayakers had lower I_{HAT} than judokas and recreational athletes, which may facilitate performing postural adjustments [12], this covariate did not affect differences between groups, and consequently kayakers' good control during unstable sitting seems to be related to their skills rather than to anthropometric differences.

Concerning the transferability of trunk stability adaptations to nonspecific testing protocols, judokas and kayakers did not show better results than recreational athletes when they were assessed using tests not designed according to their specific sport demands. Taking into account the requirement of judo training, in which judokas have to keep their balance against sudden loadings, they could be expected to obtain better results than recreational athletes on the sitting protocol but they did not. Possibly because trunk strategies used to keep balance while sitting are different from those used during judo techniques in upright stance, in which the trunk works in coordination with the lower extremities. In the same way, as kayakers have to keep their boats balanced while they are continuously disturbed by the water, they could be expected to show a better response to sudden perturbations than recreational athletes but they didn't either. Therefore, although the practice of judo and kayaking can produce some transfer of trunk stability adaptations to different tasks and contexts, in our study we did not observe such transfer. Possibly, the physical activities usually carried out by the recreational athletes (e.g., core stability exercises, free weight exercises, etc.) could also develop trunk stability adaptations reducing the differences between the recreational and the competitive athletes. Overall, these results indicate that the choice of a proper test to measure trunk stability for a given sport should be specific. Taking into account that much effort is still necessary to develop specific protocols to measure trunk stability in different competitive sports, it seems advisable to use a battery of tests to assess trunk stability.

5. Conclusions

Specialization in sports with large balance demands appears to have a significant effect on trunk stability. Competitive kayakers and judokas showed specific trunk stability adaptations, obtaining better results than recreational athletes only in those tests designed according to the specific demands of each sport.

Conflicts of interest and source of funding

The authors have no conflicts of interest to disclose.

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